# DETERMINATION OF THRESHOLD CURRENT DENSITIES FOR DIFFERENT REACTIONS OF FISHES USING A PANTOSTAT

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The threshold current densities required for first reaction, galvanotaxis and galvanonarcosis of fish depended upon species, length of the body, conductivity of water, nature of current and frequency of impulses. The threshold values and their ratios decreased with increase in length of fish. With rise in conductivity of water in the ratio of 1:4:13, these values increased in the ratio 1 : 2 : 5. Impulse D. C was superior to continuous D. C and the threshold values of current densities for different reactions of fish decreased with rise in impulse frequency reaching minimum at an impulse frequency of 48/sec. Among *Salmo irideus, Idus melanotus* and *Cyprinus carpio,* the first one was affected earlier and required minimum current densities to exhibit the reactions, while the last one showed similar reactions only at higher current densities.

## INTRODUCTION

Techniques of electrofishing have aroused great interest in many fishing countries during the last decade. Impulse currents which have a considerably greater physiological effect on living organisms than A. C and D. C and which have been used in electric shock therapy for a long time, were introduced into electrical fishing by the German Scientists Denzer and Kreutzer after the second world war. The first step of the problem was to study how the fish behaved in different forms of electric current. Houston (1949) observed that pulsating current of triangular wave shape with sharp rise and gradual fall caused fishes to place themselves with heads pointing towards the increasing potential. Groody *et al* (1952) found that saw-tooth-shaped pulses of 133 milli-seconds (ms) repeated 5 times a second were effective on sardines. Kuroki (1952) observed an increase in mean value of electric current intensity with rise of frequency in the case of *Carassius auratus.* The observations of Norman (1954) did not agree with those of Kuroki in that a pulse frequency as high as 60 to 80 per second reduced the average optimal current density to 50% of the amount required at a frequency of 5 per second. Hosel (1955) however confirmed the findings of Norman and stated that impulses of short duration reduced the power requirement considerably.

This paper is the first of a series dealing with studies on the effect of electrical field on the behaviour of *S. irideus*, *C. carpio* and *I. melanotus*, which have been carried out in the laboratory of Landesanstalt fur Fischerei, West Germany, with the aim of obtaining threshold current densities and impulse frequencies for directional swimming of fish.

## Materials and methods

A wooden trough 200 cm x 54 cm x 25 cm placed on a tubular stand was used as experimental tank. To the breadthwise ends of the tank zinc plates, 54 cm x 25 cm were attached vertically which served as electrodes. The tank was filled with water to a depth of 10 cm to form a homogeneous elcctrical field between the electrodes which were then connected to the A. C mains. The pantostat 523 (Fig 1), an electronic impulse transmitter of 60 W capacity, produced continuous D. C and impulse D. C of variable frequencies. A voltmeter connected in parallel to the terminals of electrodes indicated the potentital difference between them. The amount of current drained was recorded by a milliamperemeter attached to the pantostat Wave form of impulse D. C was checked through a cathode ray oscilloscope. A thermometer suspended from a clamp attached to the tank recorded the temperature of the water during the experiments.

The conductivity of water was measured with Siemen's conductivity meter (Fig 2) and was expressed as Siemen's

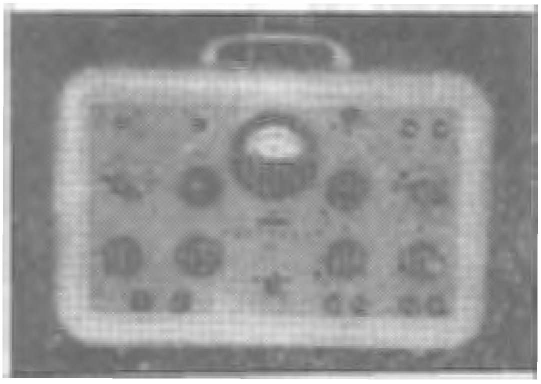

Fig 1. Siemen's Pantostat 523

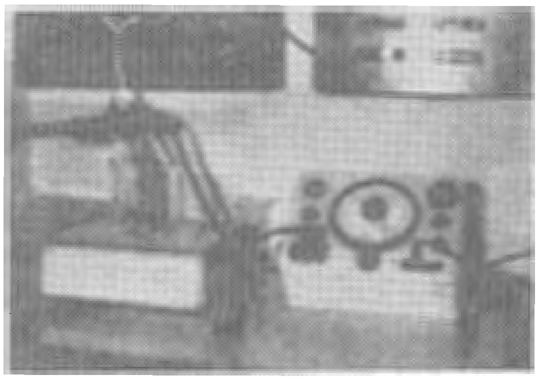

Fig 2. Siemen's conductivity meter

conductivity per cc The test fish after being acclimatised in the laboratory for 24 hrs and measured for total length, was released in the experimental tank and allowed to settle. The intensity of electrical field in the tank was raised from zero till the fish exhibited increased gill movement, expansion of dorsal, pectoral and caudal fins accompanied by tremour of the body and occasional jerks (first reaction). With the rise of current intensity beyond these visible reactions, a directional movement of the fish to the electrode (galvanotaxis) was observed when the fish lay parallel to the direction of the current But when the fish did not lie parallel to the direction of current, it first turned its head towards and then moved to the electrode. On further rise of current intensity, the fish could no longer move out and lay on its side when the intensity reached its thre-

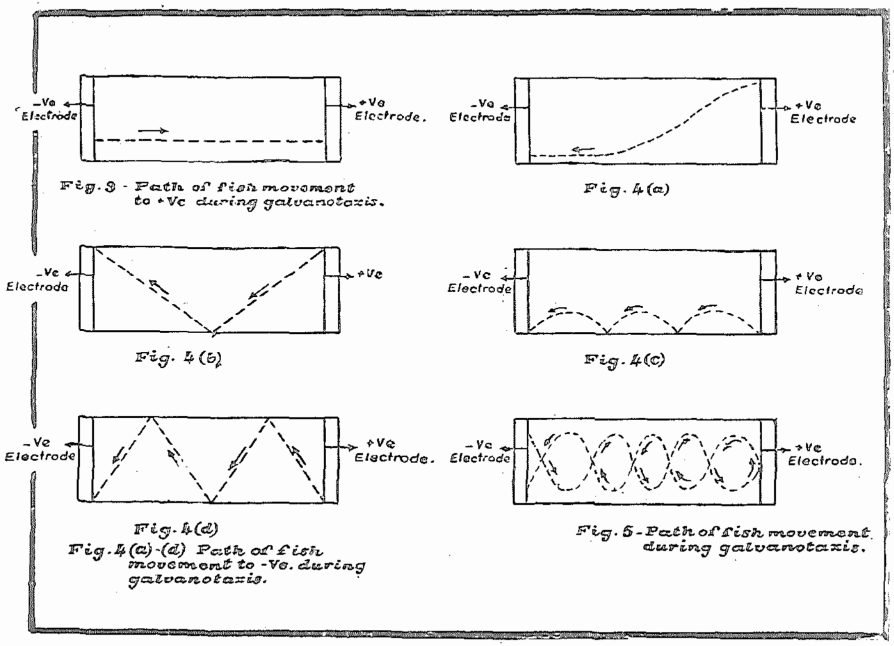


Fig. 3 - Path of fish movement to +Ve during galvanotaxis.

Fig. 4(a)

Fig. 4(b)

Fig. 4(c)

Fig. 4(d)

Fig. 4(a)-(d) Path of fish movement to -Ve. during galvanotaxis.

Fig. 5 - Path of fish movement during galvanotaxis.

shold value (galvanonarcosis). The quantity of current required for these different reactions of fish and the potential drop between the electrodes were recorded. A fresh fish was used for each experiment. The conductivity of water in the tank was raised by dissolving sodium chloride. Continuous D. C and impulse D. C were used for different series of experiments.

## Results and discussion

When a potential difference was created between the electrodes, an electrical field was set up in the water and a current started flowing from one electrode to the other, the exact magnitude and direction of which at any point depended on the shape, location of the electrodes and the boundary conditions of the conducting medium. Since the electrodes used in these experiments were plane and parallely placed in the water at a distance of 200 cm, a uniform electric field was produced in the tank. The density of current in the electric field $\delta$ was calculated as the current in $\mu$A passing through a unit area of cross section. Current density was found to be the most critical factor in producing forced directional movement of fish. The visible reactions of fish in these experiments were observed in several phases with the gradual rise of current density. The first visible reactions were increased gill movement, expansion of fins and vibration of body when the fish lay parallel to the direction of current. With the inrease in current density the fish rapidly swam towards the anode when the head was facing the anode and took a straight path (Fig 3).

The fish took an elliptical path and moved violently towards the cathode during galvanotaxis when the fish head was pointed towards the negative electrodes (Fig. 4a, d). The fish in transverse position to the current direction exhibited irregular movements between the electrodes during galvanotaxis (Fig 5). With further rise of current density the fish sank to the bottom and lay on its side ceasing all voluntary movements. Houston *(loc cit)* observed the tendency of fish to place themselves with heads pointing towards the increasing potential. Cod and herring were observed to swim to anode when released in an electrical field (Meyer–Waarden 1952).

Morgan (1953) also stated that the fish could be attracted to positive pole with interrupted D. C. Cattley (1955) described the reactions of fish in an electrical field in three definite stages which corresponded with first reaction, galvanotaxis and galvanonarcosis in the present series of experiments. The mean threshold current densities required for the three reactions in the case of *C. carpio* of various lengths at different impulse frequencies and conductivities of water are given in table 1.

In higher water conductivity, the threshold current densities for different reactions varied inversely with the length, irrespective of impulse frequencies.

The requirements of current densities for ihe three reactions in the case of *S. irideus* of different lengths are given in table 2.

Schemanzky (1938) observed the three reactions in *Phoximus laevis* with rise in current density, the ratio of which for these reactions have been calculated as 1 : 16 : 30 in fishes of length 36 mm. He also stated that not only the absolute current density decreased with increase in size of fish, but also the ratio of current densities for a particular reaction decreased with increase of fish size. *P. laevis* of median length 19 mm exhibited a mean ratio of current density of 1 : 17 : 25 for the three reactions while the corresponding ratio for fish of 66 mm length was 1:10:17.

Both *C. carpio* and *S. irideus* in the present experiments exhibited the three reactions with increase in current densities. The ratio of threshold current densities for these reactions were found to be 1 : 3 : 10 and 1 : 1 : 4 in *C. carpio* of lengths 91 mm and 230 mm, which agrees with the observations of Schemanzky *(loc cit)*. In the case of *S. irideus* of lengths 140 mm and 250 mm, the corresponding ratios were 1:3:10 and 1 : 2 : 5. Groody *et al (loc cit)*

Table I Threshold current densities for different reactions of *C. Carpio* in relation to its body length

| Length in mm | No. of fishes used | Mean threshold current density infor 1st reaction | Galvano-taxis | Galvano-narcosis |
|---|---|---|---|---|
| Impulse D. C: 34/sec. water temp: 10.5°C Siemen's conductivity of water $2x10^{-4}$/cc. | | | | |
| 91 | 3 | .008 | .023 | .067 |
| 94 | 4 | .0085 | .0305 | .073 |
| 95 | 5 | .01 | .024 | .054 |
| 96 | 2 | .013 | .025 | .052 |
| 100 | 6 | .008 | .024 | .05 |
| 242 | 4 | .005 | .015 | .037 |
| 247 | 8 | .006 | .015 | .036 |
| 250 | 5 | .004 | .015 | .036 |
| Impulse D. C: 25/sec. water temp: 15°C conductivity: $2x10^{-4}$/cc. | | | | |
| 91 | 7 | .045 | .125 | .192 |
| 92 | 4 | .042 | .086 | .163 |
| 93 | 5 | .04 | .096 | .15 |
| 94 | 6 | .04 | .089 | .17 |
| 95 | 4 | .03 | .077 | .166 |
| 98 | 4 | .029 | .067 | .163 |
| 100 | 5 | .025 | .067 | .192 |
| 241 | 3 | .009 | .029 | .11 |
| 242 | 4 | .009 | .025 | .077 |
| 245 | 6 | .008 | .03 | .086 |
| 248 | 4 | .008 | .025 | .086 |
| 250 | 5 | .006 | .025 | .057 |
| Impulse D. C: 34/sec. water temp. 10.5°C conductivity: $8x10^{-4}$/cc | | | | |
| 94 | 3 | .029 | .077 | .077 |
| 95 | 6 | .027 | .077 | .077 |
| 100 | 7 | .028 | .077 | ,077 |
| 241 | 6 | .019 | .042 | .071 |
| 250 | 12 | .017 | .038 | .061 |
| Impulse D. C: 25/sec. water temp: 10.5°C conductivity: $8x10^{-4}$/cc. | | | | |
| 91 | 4 | .059 | .121 | .121 |
| 94 | 5 | .052 | .125 | .125 |
| 95 | 6 | .05 | .125 | .125 |
| 100 | 5 | .05 | .106 | .106 |
| 224 | 7 | .035 | .086 | .163 |
| 230 | 8 | .027 | .055 | .15 |

Table II Threshold current density for different reactions of *S. irideus* in relation to its body length.

Impulse D. C: 5/sec. water temp: 20.5°C
Siemen's conductivity of water: $2x10^{-4}$/cc.

| Length in mm | No. of fishes used | Mean threshold current density infor 1st reaction | Galvano-taxis | Galvano-narcosis |
|---|---|---|---|---|
| 140 | 6 | .006 | .016 | .016 |
| 141 | 8 | .009 | .015 | .052 |
| 142 | 7 | .006 | .011 | .044 |
| 151 | 5 | .006 | .011 | .042 |
| 152 | 4 | .008 | .015 | .036 |
| 155 | 5 | .006 | .013 | .036 |
| 157 | 7 | .006 | .011 | .029 |
| 158 | 5 | .004 | .008 | .029 |
| 220 | 6 | .006 | .008 | .023 |
| 223 | 7 | .008 | .008 | .023 |
| 226 | 5 | .006 | .008 | .019 |
| 230 | 6 | .006 | .008 | .019 |
| 241 | 4 | .004 | .008 | .017 |
| 242 | 5 | .004 | .008 | .017 |
| 247 | 6 | .004 | .006 | .017 |
| 250 | 8 | .003 | .005 | .015 |

observed that the current density required to produce directional swimming in Pacific sardines varied inversely with the size of fish. Norman and Laukashkin (1954) noticed that optimal average current density required for galvanotaxis and control of movements of *Sardinops cacrulea* increased with decrease in length of fish. This observation was confirmed by Meyer-Waarden *(loc cit)* and Miyake and Steiger (1957). The latter indicated that peak current requirements for electrotaxis of *Kuhlia sandvicensis* decreased with increase in length in a pulsed direct current of square wave form. According to Harris (1953) water resistivity has a very great effect on the current density required for producing electrotaxis and paralysis.

Experiments with *S. irideus* were conducted in different water conductivities and the results are presented in table 3.

It is seen from the table that threshold current densities required to exhibit a specific reaction by this fish increased with the increase in conductivity of water, irrespective of size of fish. Though the optimum current density for a particular reaction varied directly with the increase in conductivity of water, their ratios in waters of different conductivities remained constant viz; 1 : 2 : 5. Meyer-Waarden *(loc cit)* stated that the effect of electrical field on fish was greatly dependent on conductivity of water mass.

TABLE III THRESHOLD CURRENT DENSITIES FOR DIFFERENT REACTIONS OF *S. irideus* IN RELATION TO DIFFERENT SIZES AND WATER CONDUCTIVITIES

Water temperature: 17°C Impulse D. C: 5/sec.

| Size in mm | No. of fish | Mean threshold current densities required for First reaction A | B | C | Galvanotaxis A | B | C | Galvanonaicosis A | B | C |
|---|---|---|---|---|---|---|---|---|---|---|
| 121–130 | 30 | 0.014 | 0.029 | — | 0.020 | 0 051 | — | 0.041 | 0 074 | — |
| 131–140 | 17 | 0.010 | 0 019 | — | 0 013 | 0 031 | — | 0 030 | 0 050 | — |
| 141–150 | 47 | 0.011 | 0 019 | 0 042 | 0.017 | 0.036 | 0 090 | 0 049 | 0 089 | 0.385 |
| 151–160 | 46 | 0 008 | 0 017 | 0 029 | 0.015 | 0.037 | 0.072 | 0 050 | 0 094 | ,, |
| 161–170 | 41 | 0.006 | 0 014 | 0.027 | 0 013 | 0 031 | 0 065 | 0 046 | 0.074 | 0.382 |
| 171–180 | 34 | ,, | 0.011 | ,, | 0.012 | 0 025 | ,, | 0.045 | 0.071 | ,, |
| 181–190 | 31 | ,, | 0.014 | ,, | ,, | 0 028 | 0.064 | 0.049 | 0.084 | 0.381 |
| 191–200 | 36 | 0 004 | ,, | ,, | ,, | 0.026 | ,, | 0.057 | 0.072 | 0.374 |
| 201–210 | 34 | 0.003 | 0.009 | 0.025 | 0.010 | 0.025 | 0.061 | ,, | 0.076 | 0.372 |

A: Siemen's conductivity : $2\ 0x10^{-4}$/cc, B: $7.6x10^{-4}$/cc, C: $26.0x10^{-4}$/cc.

The optimum current densities required for first reaction, galvanotaxis and galvanonarcosis of *I.melanotus* and *C. carpio* of different lengths are shown in table 4. The threshold current densities for different reactions increased with rise in conductivity of water irrespective of impulse frequencies in both cases. Houston *(loc cit)* and Meyer–Waarden (1953) reported that impulse current has greater physiological effects on fishes than ordinary A. C and continuous D. C. Morgan *(loc cit)* confirmed the superiority of interrupted D. C over continuous D. C not only with respect to increased electrotactic and electronarcotic effects on fishes but also due to attraction of the fish to the positive pole.

Optimum current densities required for exhibiting the first reaction in the case of *S. irideus* of different lengths in continuous D. C; impulse D. C of different frequencies and at different conductivities of water are shown in table 5.

The corresponding values required for galvanotaxis and galvanonarcosis are shown in tables 6 and 7 respectively.

These values not only prove the superiority of impulse D. C over continuous D. C but also show the reduction in the requirement of electric power with the former.

Houston *(loc cit)*, using impulse D. C of triangular wave shape having frequencies of 2 to 20 pulses per second with impulse duration of 2 ms, could regulate the size and type of fishes caught by varying the pulse rates. Best effect was obtained by Kreutzer *(loc cit)* with impulse current of sudden increase and slow decrease and duration of 2 ms, when small fishes showed best results with 20 shocks per second and larger fishes with 2 shocks per second.

In the present studies, impulse D. C of square wave form having frequencies between 26 and 48 per second with varying impulse duration from 1 to 18 ms and

TABLE IV THRESHOLD CURRENT DENSITIES FOR DIFFERENT REACTIONS OF *I. melanotus* AND *C. carpio* IN RELATION TO DIFFFRENT WATER CONDUCTIVITIES

Water temperature: 16°C Name of fish: *I melanotus*

| Size in mm | No. of fish | Impulse D. C. frequency/sec. | Mean threshold current densities required for First reaction A | First reaction B | Galvanotaxis A | Galvanotaxis B | Galvanonarcosis A | Galvanonarcosis B |
|---|---|---|---|---|---|---|---|---|
| 171–180 | 18 | 38 | 0 008 | 0.021 | 0 015 | 0 046 | 0 027 | 0 063 |
| 181–190 | 19 | ,, | 0.008 | 0.021 | 0 015 | 0.038 | 0 023 | 0 059 |
| 191–200 | 21 | ,, | 0 006 | 0 017 | 0.015 | 0.035 | 0 021 | 0.055 |
| 171–180 | 17 | 26 | 0.029 | 0.033 | 0 035 | 0 059 | 0 083 | 0 117 |
| 181–190 | 16 | ,, | 0.021 | 0.025 | 0.033 | 0.057 | 0.065 | 0 115 |
| 191–200 | 15 | ,, | 0.019 | 0.023 | 0 029 | 0 042 | 0.061 | 0 086 |
| 171–180 | 21 | 25 | 0.029 | 0.040 | 0 035 | 0.067 | 0 096 | 0.132 |
| 181–190 | 21 | ,, | 0.021 | 0.025 | 0.033 | 0.059 | 0.077 | 0.115 |
| 191–200 | 19 | ,, | ,, | 0.023 | ,, | 0.057 | 0.065 | 0.106 |
| Name of fish: *C. carpio* | | | | | | | | |
| 91–100 | 18 | 38 | 0.009 | ,, | 0 027 | 0.071 | 0 057 | 0 075 |
| 241–250 | 19 | ,, | 0 006 | 0.019 | 0 015 | 0:036 | 0 042 | 0 069 |
| 91–100 | 18 | 25 | 0.031 | 0.073 | 0.085 | 0.123 | 0 179 | 0 157 |
| 241–150 | 19 | ,, | 0.013 | 0.044 | 0.033 | 0.100 | 0 092 | 0.125 |

A: Siemen's conductivity $2x10^{-4}$/cc
B: ,, ,, 8x ,,

Table V Threshold current densities required for first reation in *S. irideus* in relation to type of current, impulse frequency and water conductivity

Water temp : 16°C Pause duration : 20 ms Siemen's conductivity : $2x10^{-4}$/cc

| Size in mm | No. of fish | Mean threshold current densities in $\delta$ required for 1st reaction in D.C and impluse currents | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D.C | I | II | III | IV | V | VI |
| 111–120 | 21 | 0.048 | 0.0008 | 0.006 | 0.009 | 0.012 | 0.015 | 0.019 |
| 121–130 | 18 | 0.046 | 0.0006 | 0.005 | 0.008 | 0.010 | 0.014 | 0.019 |
| 131–140 | 19 | 0 044 | ,, | 0.004 | ,, | ,, | 0.011 | 0.017 |
| 141–150 | 21 | 0.042 | 0.0004 | 0.002 | 0.006 | 0.009 | ,, | 0.016 |
| 151–160 | 19 | ,, | ,, | ,, | ,, | ,, | 0.010 | 0.015 |
| 161–170 | 19 | 0.040 | ,, | ,, | 0.004 | 0.008 | ,, | ,, |
| 171–180 | 21 | ,, | ,, | 0.001 | ,, | ,, | 0.008 | 0.014 |
| 181–190 | 21 | 0.039 | ,, | ,, | ,, | 0.006 | ,, | 0.012 |
| Siemen's conductivity : $7.5x10^{-4}$/cc | | | | | | | | |
| 121–130 | 16 | | | | 0.019 | 0.021 | 0.024 | |
| 131–140 | 18 | | | | ,, | 0.019 | 0.021 | |
| 141–150 | 19 | | | | 0.017 | 0.017 | 0.019 | |
| 151–160 | 15 | | | | 0 012 | 0.012 | ,, | |
| 161–170 | 16 | | | | ,, | ,, | 0.018 | |
| 171–180 | 21 | | | | 0.011 | 0.011 | 0.016 | |
| 181–190 | 13 | | | | 0.010 | ,, | 0.013 | |
| 191–200 | 13 | | | | 0.009 | 0.010 | ,, | |
| 201–210 | 15 | | | | ,, | 0.009 | 0.009 | |

Table VI Threshold current densities required for galvanotaxis in *S. irideus* in relation to type of current, impulse frequency and water conductivity.

Water temp : 16°C Pause duration : 20 ms Siemen's conductivity : $2x10^{-4}$/cc

| Size in mm | No. of fish | Mean threshold current densities in $\delta$ required for galvanotaxis in D.C. and impulse currents | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D.C | I | II | III | IV | V | VI |
| 111–120 | 21 | 0.153 | 0.002 | 0.015 | 0.018 | 0.021 | 0.025 | 0.046 |
| 121–130 | 18 | 0.110 | ,, | ,, | ,, | ,, | 0.024 | ,, |
| 131–140 | 19 | 0.100 | ,, | 0.012 | ,, | ,, | ,, | 0.036 |
| 141–150 | 21 | 0.096 | 0.001 | ,, | 0.014 | 0.019 | 0 023 | ,, |
| 151–160 | 19 | 0.086 | ,, | 0.011 | ,, | 0.017 | 0.019 | 0.031 |
| 161–170 | 19 | 0.055 | ,, | ,, | 0.013 | 0.015 | 0.017 | 0.030 |
| 171–180 | 21 | 0.046 | 0.0008 | ,, | 0.012 | 0.014 | 0.015 | 0.027 |
| 181–190 | 21 | 0.044 | 0 0006 | 0.010 | 0.011 | 0.013 | 0.014 | 0.023 |
| Siemen's conductivity : $7.6x10^{-4}$/cc | | | | | | | | |
| 121–130 | 16 | | | | 0.027 | 0.029 | 0.046 | |
| 131–140 | 18 | | | | ,, | ,, | ,, | |
| 141–150 | 19 | | | | 0.021 | 0.027 | 0.042 | |
| 151–160 | 15 | | | | ,, | ,, | ,, | |
| 161–170 | 16 | | | | 0.019 | 0.025 | 0.041 | |
| 171–180 | 21 | | | | ,, | ,, | 0.036 | |
| 181–190 | 14 | | | | 0.018 | 0.024 | 0.029 | |
| 191–200 | 13 | | | | 0.017 | 0.023 | 0.027 | |
| 201–210 | 15 | | | | 0.017 | 0.021 | 0.025 | |

I : 48 impulses/sec for 1 ms
II : 43 ,, ,, 3 ,,
III : 38 ,, ,, 6 ,,
IV : 34 impulses/sec for 9 ms
V : 31 ,, ,, 12 ,,
VI : 26 ,, ,, 18 ,,

Table VII Threshold current densities required for galvanonarcosis in *S. irideus* in relation to type of current, impulse frequency and water conductivity.

Water temp: 16°C Pause duration : 20 ms Siemen's conductivity : $2x10^{-4}$/cc.

| Size in mm | No. of fish | Mean threshold current densities in $\delta$ required for galvanonarcosis in D.C. and impulse currents D.C | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|---|---|
| 111-120 | 21 | 0.163 | 0.013 | 0.019 | 0.031 | 0.038 | 0.050 | 0.057 |
| 121-130 | 18 | 0.153 | 0.012 | 0.017 | 0.030 | ,, | ,, | ,, |
| 131-140 | 19 | ,, | 0.009 | 0.015 | 0.029 | 0.037 | 0.047 | 0.056 |
| 141-150 | 21 | 0.150 | ,, | ,, | 0.027 | ,, | ,, | ,, |
| 151-160 | 19 | 0.144 | 0.008 | 0.014 | ,, | ,, | 0.044 | ,, |
| 161-170 | 19 | 0.136 | 0.007 | 0.013 | 0.025 | 0.036 | 0.042 | 0.055 |
| 171-180 | 21 | 0.121 | ,, | ,, | 0.024 | ,, | 0.040 | ,, |
| 181-190 | 21 | 0 110 | 0.006 | 0.010 | 0.023 | ,, | 0.038 | 0.050 |
| | | Siemen's conductivity : $7.6x10^{-4}$/cc | | | | | | |
| 121-130 | 16 | | | | 0.057 | 0.077 | 0.11 | |
| 131-140 | 18 | | | | 0.055 | ,, | 0.098 | |
| 141-150 | 19 | | | | 0.054 | 0.076 | 0.096 | |
| 151-160 | 15 | | | | 0.052 | 0.075 | 0.094 | |
| 161-170 | 16 | | | | 0.050 | 0.074 | 0.092 | |
| 171-180 | 21 | | | | 0.048 | ,, | ,, | |
| 181-190 | 14 | | | | 0.046 | 0.067 | 0.090 | |
| 191-200 | 13 | | | | ,, | 0.057 | 0.067 | |
| 201-210 | 15 | | | | ,, | ,, | ,, | |

I : 48 impulses/sec for 1 ms
II : 43 ,, ,, 3 ,,
III : 38 ,, ,, 6 ,,
IV : 34 impulses/sec for 9 ms
V : 31 ,, ,, 12 ,,
VI : 26 ,, ,, 18 ,,

constant pause duration of 20 ms was used. The optimum current densities required for the three reactions of *S. irideus* were found to vary inversely with rise of impulse frequency (Tables 5 to 7). While observing the behaviour of *Carassius arratus* under the influence of low frequency electric shocks, it was noticed that the mean value of electric current intensity increased with the increase of frequency of impulses. While Kreutzer and Peglow (1951) found that a square wave pulse of 2 ms repeated 50 times a second is very effective on cod and herring, Groody *et al (loc cit)* observed the effectiveness of saw-tooth-shaped pulses of 133 ms repeated 5 times a second on sardines.

The threshold current densities required for first reaction in *I. Melanotus* of different lengths increased with decrease of impulse frequencies in water having conductivity of $2 \times 10^{-4}$ /cc. In a higher conductivity of $7.6 \times 10^{-4}$ /cc, the values rose with decrease of Impulse frequencies in fishes of similar size grades. The threshold values of current densities for the second and third reactions varied inversely with the rise of impulse frequency irrespective of size of fishes and conductivity of water. These results are shown in table 8.

Morgan (*loc cit*) observed that the peak current value reached during a pulse was an important factor influencing the response of fish to the current. The present series of experiments were aimed at determining the minimum peak current

Table VIII Threshold current densities required for the reactions in *I melanotus* in relation to impulse frequency and water conductivity

Water temp : 16°C    Pause duration : 20 ms    Siemen's conductivity : $2x10^{-4}$/cc

| Size in mm | No. of fish | Mean threshold current density in δ for 1st reaction A | B | C | D | Mean threshold current density in δ for galvanotaxis A | B | C | D | Mean threshold current density in δ for galvanonarcosis A | B | C | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 161—170 | 25 | 0.006 | 0.009 | 0.029 | 0.029 | 0.012 | 0.042 | 0.042 | 0.042 | 0.021 | 0.027 | 0.083 | 0.096 |
| 171—180 | 24 | ,, | 0.008 | 0.021 | 0.021 | 0.011 | 0 015 | 0.035 | 0.040 | 0.019 | 0.023 | 0.065 | 0.077 |
| 181-190 | 18 | ,, | ,, | ,, | ,, | ,, | 0.014 | ,, | 0.035 | 0.017 | 0.021 | ,, | 0.065 |
| 191-200 | 21 | 0.005 | 0.006 | 0.019 | 0.020 | 0.010 | 0.013 | 0.029 | ,, | ,, | ,, | 0.061 | ,, |
| Siemen's conductivity : $7.6x10^{-4}$/cc | | | | | | | | | | | | | |
| 161-170 | 22 | 0.021 | 0.023 | 0.033 | 0.046 | 0.046 | 0 053 | 0.053 | 0.059 | 0.086 | 0.063 | 0.117 | 0.155 |
| 171-180 | 20 | 0.020 | ,, | 0.030 | 0.040 | 0.042 | 0.050 | 0.057 | 0.083 | 0.060 | 0.092 | 0.115 | 0.132 |
| 181-190 | 18 | 0.017 | 0 021 | 0.025 | 0.038 | 0.040 | 0.046 | 0.055 | 0.080 | 0.059 | 0.086 | 0 110 | 0.130 |
| 191-200 | 16 | ,, | 0.017 | 0.023 | 0.025 | 0.035 | 0.038 | 0.042 | 0.067 | 0.055 | 0.084 | 0.086 | 0.106 |

A : 34 impulses/sec for 9 ms    B : 31 impulses/sec for 12 ms    C : 26 impulses/sec for 18 ms    D : 25 impulses/sec for 20 ms

Table IX Threshold current densities required for reactions in relation to species and conductivity

Water temp : 16°C    Impulse frequency : 25/sec.    Impulse duration 20 ms    Pause duration : 20 ms
Siemen's conductivity : $2x10^{-4}$/cc

| Size in mm | No. of fish | Mean threshold current density in δ for 1st reaction I | II | III | Mean threshold current density in δ for galvanotaxis I | II | III | Mean threshold current density in δ for galvanonarcosis I | II | III |
|---|---|---|---|---|---|---|---|---|---|---|
| 161-170 | 24 | 0.015 | 0.029 | 0 030 | 0.030 | 0 042 | 0.058 | 0.055 | 0.096 | 0.115 |
| 171-180 | 18 | 0.014 | 0.021 | 0.029 | 0.027 | 0.040 | 0.056 | ,, | 0.077 | 0.110 |
| 181-190 | 21 | 0.012 | ,, | 0.028 | 0.023 | 0.035 | 0.055 | 0.050 | 0.065 | 0.100 |
| 191-200 | 24 | 0.010 | 0.020 | ,, | 0 025 | ,, | 0.050 | ,, | ,, | ,, |
| Siemen's conductivity : $8x10^{-4}$/cc | | | | | | | | | | |
| 161-170 | 18 | | 0.046 | 0 059 | | 0.086 | 0.110 | | 0.155 | 0.157 |
| 171-180 | 15 | | 0.040 | 0.058 | | 0.083 | 0.100 | | 0 132 | 0.145 |
| 181-190 | 12 | | 0.038 | 0.055 | | 0.080 | 0.095 | | 0.130 | 0.140 |
| 191-200 | 12 | | 0.025 | 0.050 | | 0.067 | 0.090 | | 0.106 | 0.135 |

I : *irideus*    II : *I. melanotus*    III : *C. carpio* value required by fishes to exhibit different reactions in electric field. Norman *(loc cit)* while describing the behaviour of sardine in electric field, observed that any frequency of current pulsation from 2 to 80 per second can have full control over fish movement in directional swimming. A pulse frequency as high as 60 to 80 per second reduces the average optimal current density to 50% of the amount required at a frequency of 5 per second. Hosl *(loc cit)* observed that impulse current of 1 ms duration and interruption of 9 ms has greater physiological effect on fish than D. C or A. C of 50 c/s.

The threshold current densities required for the three reactions in *S. irideus* *I.melanotus* and *C.carpio* of different lengths at two different water conductivities are shown in table 9.

The values for *S. irideus* were the minimum and those for *C. carpio* the maximum which was in conformity with the observation of Meyer-Waarden *(loc cit)* who found that these values were specific for species and size of fish.

## Conclusions

The first reaction, galvanotaxis and galvanonarcosis in fishes occur only when the current density in the surrounding field has reached a specific value dependent on length of fishes, conductivity of water, nature of current, impulse frequency and variety of fishes. It is found in *S. irideus* and *C. carpio* that the values of optimum current densities vary inversely with length of the fish. The mean ratio of current densities required for different reactions of *C. carpio* and *S. irideus* decreases with increase of fish length, decreasing from 1 : 3 : 10 in *S. irideus* of 140 mm length to 1 : 2 : 5 in the same fish of 250 mm length. The current densities increase with rise in conductivity of water. Impulse D. C is more effective than continuous D. C. The values decrease with increase of impulse frequencies reaching a minimum at 48 impulses per second in water conductivity of $2 \times 10^{-4}$/cc. In higher conductivities the threshold values decreased with increase in impulse frequencies. The values are also specific for different species of fish.

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